The Journal of Emergency Medicine, Vol. ■, No. ■, pp. 1–14, 2017
Published by Elsevier Inc.
0736-4679/$ - see front matter

ELSEVIER

http://dx.doi.org/10.1016/j.jemermed.2017.08.026

Clinical Review

CAPNOGRAPHY IN THE EMERGENCY DEPARTMENT: A REVIEW OF USES, WAVEFORMS, AND LIMITATIONS

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☐ **Abstract—Background: Capnography has many uses in the emergency department (ED) and critical care setting, most commonly cardiac arrest and procedural sedation. Objective of the Review: This review evaluates several indications concerning capnography beyond cardiac arrest and procedural sedation in the ED, as well as limitations and specific waveforms. Discussion: Capnography includes the noninvasive measurement of CO_2, providing information on ventilation, perfusion, and metabolism in intubated and spontaneously breathing patients. Since the 1990s, capnography has been utilized extensively for cardiac arrest and procedural sedation. Qualitative capnography includes a colorimetric device, changing color on the amount of CO_2 present. Quantitative capnography provides a numeric value (end-tidal CO_2), and capnography most commonly includes a waveform as a function of time. Conditions in which capnography is informative include cardiac arrest, procedural sedation, mechanically ventilated patients, and patients with metabolic acidemia. Patients with seizure, trauma, and respiratory conditions, such as pulmonary embolism and obstructive airway disease, can benefit from capnography, but further study is needed. Limitations include use of capnography in conditions with mixed pathophysiology, patients with low tidal volumes, and equipment malfunction. Capnography should be used in conjunction with clinical assessment. Conclusions: Capnography demonstrates benefit in cardiac arrest, procedural sedation, mechanically ventilated patients, and patients with metabolic acidemia. Further study is required in patients with seizure, trauma, and respiratory conditions. It should only be used in conjunction with other patient factors and clinical assessment.**

☐ **Keywords—capnography; capnometer; carbon dioxide; end-tidal; monitoring; resuscitation; waveform**

INTRODUCTION

Breathing consists of oxygenation and ventilation. Oxygenation can be assessed with pulse oximetry, while capnography provides information on ventilation (effectiveness of carbon dioxide [CO_2] elimination), perfusion (CO_2 transportation in vasculature), and metabolism (production of CO_2 via cellular metabolism) (1–8).

Capnography includes the noninvasive measurement of CO_2 partial pressure during the breathing cycle. Capnography and capnometry are often used interchangeably, though they are distinct entities. Capnography is a comprehensive measurement and display of CO_2, including end-tidal and inspired CO_2 as a number and waveform. A capnometer displays a numeric value for CO_2 on a monitor. The CO_2 waveform is most commonly displayed as a function of time, though critical care uses include graphs with the waveform as a function of volume (1–8). One of the first studies utilizing exhaled CO_2 was conducted in the 1970s (9). Since the 1990s, capnography has been used for an increasing

RECEIVED: 21 July 2017;
ACCEPTED: 11 August 2017

number of conditions, procedures, and monitoring (1–4,8). The concentration of CO_2 vs. time represents the CO_2 waveform, and changes in this shape can assist physicians in a variety of conditions, including assessment of disease severity, cardiac arrest (compression quality, return of spontaneous circulation, endotracheal tube placement, prognosis, among others), procedural sedation, and critical illness (1–4,7,8).

Capnography measures CO_2 partial pressure by mainstream or side-stream device. Mainstream devices measure CO_2 directly from the airway, most commonly with the sensor housed directly in the respiratory circuit, and these devices are used for intubated and spontaneously breathing patients. Sidestream devices measure CO_2 by sampling exhaled breath through a side port and can be used for intubated and spontaneously breathing patients as well (2–4,8,10,11).

Qualitative monitors include a colorimetric end-tidal CO_2 ($EtCO_2$) device, which changes color depending on amount of CO_2 present (8,10,11). This color change occurs due to the pH of carbonic acid that is formed as a product of the reaction between carbon dioxide and water. The device is purple for EtCO2 < 3–4 mm Hg (< 0.5%), tan for 3–15 mm Hg (0.5%–2%), and yellow for values > 15 mm Hg (> 2%) (1–4,8,10,11). Quantitative monitors utilize infrared radiation, as CO_2 absorbs a specific wavelength of radiation, allowing photodetectors to calculate CO_2 concentration in the sample (2–4,8–11).

A capnogram consists of two primary components, inspiratory and expiratory, which can be further broken into four different phases (2–4,8–11). This is demonstrated in Table 1, with Figure 1 displaying a normal waveform.

Interpretation requires consideration of three aspects of capnography: the $EtCO_2$ maximum number or plateau, the shape of the capnogram, and the difference or gradient between $EtCO_2$ and arterial CO_2 pressure (6–8,10,11). Normal ventilation and lung function demonstrate a rectangular waveform. Factors that affect capnography include CO_2 production, CO_2 transport, ventilation, and ventilation to perfusion ratio changes. Ventilator settings and malfunctions, disconnections and leaks, tubing obstruction, sampling method and site, sample rate, and monitor malfunctions can also affect capnography readings. The maximum PCO_2 at end expiration is the $EtCO_2$, which varies normally between 35 and 40 mm Hg. The gradient between arterial CO_2 and alveolar CO_2 is approximately 3–5 mm Hg in healthy patients, due to the combination of dead space CO_2 and alveolar CO_2 (1–5,8,10,11). This gradient functions as a surrogate for assessing ventilation–perfusion relationship (1–5,8,10,11).

Table 1. Capnography Phases

Segment	Phase	Explanation
Inspiration	0	Inspiration begins, with clearing of CO_2
	β-angle	Located between phase III and descending part of inspiration, normally 90 degrees
Expiration	I	Consists of anatomical dead space Should not contain CO_2
	II	Rapid rise in CO_2 concentration as the breath reaches upper airway from the alveoli Mixture of anatomical and alveolar dead space
	III	Alveolar plateau CO_2 concentration reaches uniform levels in the airway Height and slope of the line offers important information on the ventilation and perfusion ratios in the lungs Height related to cardiac output
	α-angle	Located between phase II and III, normally 100 degrees

METHODS

The authors conducted a literature search of Medline, EBSCO, and Google Scholar for search terms including *capnography, capnogram, interpretation, cardiac arrest, procedural sedation, end-tidal, return of spontaneous circulation, trauma, injury, metabolic acidosis/acidemia, critical illness, pulmonary embolism, seizure, sepsis,* and *obstructive airway disease*. Studies were limited to those evaluating human subjects in English from 1980 to 2017. The authors agreed on articles to include by consensus. This review is not a systematic review or meta-analysis, and study quality was not assessed formally with a standardized tool.

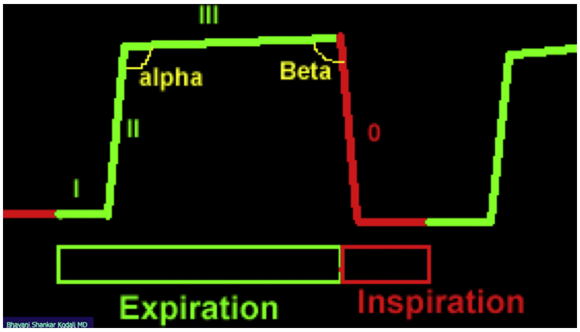

Figure 1. Normal capnography waveform. Reprinted from: http://www.capnography.com/new/encyclopedia, with permission.